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DESULPHURIZATION OF COAL: REVIEW OF LITERATURE, ANALYSES OF CAPE BRETON COALS, AND RELATION BETWEEN TOTAL AND PYRITIC IRON

by

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1. Review of Literature

The following papers are considered to be relevant to the desulphurization of Cape Breton coals. Copies of these papers are on open file (01-B.2.9) at the Metals Reduction and Energy Centre, 562 Booth Street, Ottawa.

(1) "Basic Methods of Removing Sulfur from Coal", by Joseph W. Leonard and Charles F. Cockrell, Mining Congress Journal, December, 1970, p. 65-70.

(2) "The Search for Low-Sulfur Coal", by Harry Perry and Joseph A. Decarlo, Mechanical Engineering, April 1967, p. 22-28.

(3) "Reduction of Sulfur in Minus 28 Mesh Bituminous Coal", by F.G. Miller, Society of Mining Engineers, March, 1964, p. 7-15.

(4) "Removal of Pyritic Sulphur from Coal by Bacterial Action", by M.P. Silverman, M.H. Rogoff and I. Wender, U.S. Bureau of Mines, 1962 (No journal reference available).

(5) "Study of Fine Coal Cleaning Process by Automatic Microscopy", by D.R. Bomberger and M. Deul, Society of Mining Engineers, March, 1964, p. 65-69.

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*Head, Laboratory Services Section, Metals Reduction and Energy Centre, Department of Energy, Mines and Resources, Mines Branch, Ottawa, Canada.

(6) "Predicted Results of Cleaning Appalachian Coals at Low Density for Sulfur Reduction", by M.R. Geer, USBM Report of Investigations 7098, Washington, D.C.

2. Analyses of Cape Breton Coals

Tables 1, 2, 3 and 4 contain analyses of coal samples from DEVCO's Lingan Mine, Princess Mine, and #26, #20 and #12 Collieries respectively.

These samples were collected and analysed by the staff of the Fuels Research Centre. Based on the detailed analysis of Lingan Mine coal, two computations were performed.

(1) What is the relationship between the total iron present and the iron associated with pyrite?

1) calculate Fe associated with pyritic S.

2) calculate Fe associated with Fe_2O_3 from the ash analysis.

3) convert this as a percentage of the ash in the coal which is then the total iron in the coal.

4) the difference between the total Fe in the coal and the Fe associated with pyrite indicates the % Fe associated with other minerals.

- see Table 5 for data and calculated values.

Table 1 - Cape Breton Development Corporation - Lingan Mine

Identification									
Laboratory Number	2995-71	2917-71	2780-71	2765-72	2654-71	2505-71	2504-71	2360-71	2183-72
Description	Field Mark L-J-71	Field Mark L-I-71		Mark L-B-72	Mark L-G-71	Bulk Channel Sample	Slack 1¼ sqx0	Bulk Channel from #3 Slope	Field Mark L-H-72
Classification									
Rank (ASTM)	hvAb	hvAb	hvAb	hvAb	hvAb	hvAb	hvAb	hvAb	hvAb
Specific Volatile Index	162	158	156	161	157	159	171	159	161
Volatile Matter (dmmfb) ....%	38.29	37.77	39.68	40.77	39.94	41.51	40.06	39.75	39.89
Carbon (dmmfb) .....%	84.62	81.14	83.41	84.00	84.39	83.65	86.29	84.32	84.25
Proximate Analysis (db)									
Ash .....%	3.54	4.04	4.81	5.15	6.29	4.43	5.40	3.89	3.82
Volatile Matter .....%	37.26	36.57	38.24	39.15	37.93	40.08	38.39	38.54	38.71
Fixed Carbon .....%	59.20	59.39	56.95	55.70	55.78	55.49	56.21	57.57	57.47
Gross Calorific Value (db)									
Btu per pound	14524	14321	14097	14232	13930	14292	14582	14389	14473
Ultimate Analysis (db)									
Carbon .....%	81.18	81.25	78.75	78.99	78.38	79.36	80.92	80.57	80.55
Hydrogen .....%	5.17	5.30	5.21	5.25	5.14	5.39	5.37	5.46	5.27
Sulphur .....%	1.61	1.25	3.02	2.96	1.98	2.59	2.81	2.21	1.86
Nitrogen .....%	1.61	0.84	1.52	1.73	1.60	1.59	1.51	1.51	1.64
Ash .....%	3.54	4.04	4.81	5.15	6.29	4.43	5.40	3.89	3.82
Oxygen (by difference) ....%	6.89	7.32	6.69	5.92	6.61	6.64	3.99	6.16	6.86
Ash Analysis (db)									
SiO_2 .....%	30.01	42.04	20.42		37.10	20.86	17.44	19.89	
Al_2O_3 .....%	21.53	25.67	15.90		22.35	17.12	15.32	17.11	
Fe_2O_3 .....%	45.20	27.52	59.79		35.27	59.60	36.34	60.45	
TiO_2 .....%	0.60	0.91	0.46		0.64	0.71	0.63	0.10	

Table 1 - Cape Breton Development Corporation - Lingan Mine Cont'd

Ash Analysis (db) Cont'd									
P_2O_5 .....%	0.28	0.15	0.33		0.20	0.26	0.19	0.17	
CaO .....%	1.19	1.12	0.84		0.94	0.98	9.94	1.05	
MgO .....%	0.93	1.16	0.41		0.96	0.34	4.90	0.40	
SO_3 .....%	0.35	0.25	0.40		0.73	0.76	14.52	0.93	
Na_2O .....%	0.44	0.44	0.39		0.48	0.29	0.53	0.53	
K_2O .....%	1.03	1.55	0.44		1.77	0.66	0.59	0.44	
Forms of Sulphur (db)									
Sulphate .....%	0.03	0.00	1.03	0.09	0.03	0.11	0.09	0.10	0.02
Pyritic .....%	1.18	0.65	1.68	2.13	1.56	1.97	1.66	1.46	1.38
Organic (by difference) ...%	0.40	0.60	0.31	0.74	0.39	0.51	1.06	0.65	0.46
Total .....%	1.61	1.25	3.02	2.96	1.98	2.59	2.81	2.21	1.86
Free Swelling Index	5½	6½	6	4½	6½	5½	6½	5	5½

Table 2 - Cape Breton Development Corporation - Princess Mine

Identification					
Laboratory Number					
Description	Nut 1¾x¾ rd	Egg + 1¾ rd	Coarse Slack 1¾ rd	Pea ¾x¼ slot	Fines ¼x0 slot
Classification					
Rank (ASTM)					
Specific Volatile Index					
Volatile Matter (dmmfb) .....%					
Carbon (dmmfb) .....%					
Proximate Analysis (db)					
Ash .....%	5.50	6.83	14.43	14.69	3.53
Volatile Matter .....%	38.41	38.19	35.19	34.12	37.19
Fixed Carbon .....%	56.09	54.98	50.38	51.19	59.28
Gross Calorific Value (db)					
Btu per pound	14530	14260	13038	12951	14737
Ultimate Analysis (db)					
Carbon .....%					
Hydrogen .....%					
Sulphur .....%					
Nitrogen .....%	3.25	3.52	3.26	2.84	2.98
Ash .....%					
Oxygen (by difference).....%					
Ash Analysis (db)					
SiO_2 .....%	25.58	32.43	45.52	46.43	22.68
Al_2O_3 .....%	19.36	20.72	27.12	28.00	17.91

Table 2 - Cape Breton Development Corporation - Princess Mine Cont'd

Ash Analysis (db) Cont'd					
Fe_2O_3 .....%	50.79	41.95	21.43	19.20	54.29
TiO_2 .....%	0.66	0.68	0.65	0.73	0.57
P_2O_5 .....%	0.27	0.25	0.18	0.16	0.32
CaO .....%	1.25	0.92	0.95	0.87	1.68
MgO .....%	0.44	0.91	0.95	1.30	0.75
SO_3 .....%	1.15	0.92	0.68	0.84	2.15
Na_2O .....%	0.78	0.58	0.82	0.78	0.29
K_2O .....%	1.10	1.62	3.24	3.39	0.81
Forms of Sulphur					
Sulphate .....%					
Pyritic .....%					
Organic (by difference).%					
Total .....%					
Free Swelling Index	5¾	5½	6	6	6

Table 3 - Cape Breton Development Corporation - #26 and #20 Collieries

Identification				
Laboratory Number				
Description	#26 Mine Slack 4x0	#26 Colliery Screened +4"	#26 Colliery Pea ⅜x5/16	#20 Colliery Slack 1½x0
Classification				
Rank (ASTM)				
Specific Volatile Index	173	175	172	172
Volatile Matter (dmmfb) ....%	37.00	37.84	36.94	38.31
Carbon (dmmfb) .....%	86.55	86.34	85.99	85.88
Proximate Analysis (db)				
Ash .....%	2.83	2.73	6.79	6.11
Volatile Matter .....%	36.19	37.02	34.92	36.54
Fixed Carbon .....%	60.98	60.25	58.29	57.35
Gross Calorific Value (db)				
Btu per pound	15053	15156	14317	14450
Ultimate Analysis (db)				
Carbon .....%	83.78	83.68	79.48	79.84
Hydrogen .....%	5.44	5.51	5.22	5.27
Sulphur .....%	0.82	0.80	1.00	3.13
Nitrogen .....%	1.60	1.80	1.64	1.44
Ash .....%	2.83	2.73	6.79	6.11
Oxygen (by difference) .....%	5.53	5.48	5.87	4.21
Ash Analysis (db)				
SiO_2 .....%	32.98	36.75	46.59	33.55
Al_2O_3 .....%	25.58	25.10	27.50	22.15

Table 3 - Cape Breton Development Corporation - #26 and #20 Collieries Cont'd

Ash Analysis (db) Cont'd				
Fe_2O_3 .....%	32.60	30.74	18.55	37.25
TiO_2 .....%	0.66	0.64	0.70	0.59
P_2O_5 .....%	0.25	0.31	0.18	0.20
CaO .....%	3.29	2.73	1.40	2.66
MgO .....%	1.80	1.60	1.60	0.80
SO_3 .....%	2.25	1.77	1.02	1.94
Na_2O .....%	0.97	0.87	0.87	0.78
K_2O .....%	1.32	1.18	2.65	1.18
Forms of Sulphur				
Sulphate .....%				
Pyritic .....%				
Organic (by difference) .....%				
Total .....%				
Free Swelling Index	7½	6½	7½	7½

Table 4 - Cape Breton Development Corporation - #12 Colliery

Identification				
Laboratory Number				
Description	#12 Colliery Screened +2" sq	#12 Colliery Special Slack 2x0	#12 Colliery Regular Slack 2x0	#12 Colliery Fines ¼x0
Classification				
Rank (ASTM)				
Specific Volatile Index	174	181	178	181
Volatile Matter (dmmfb) .....%	38.28	36.88	37.31	36.24
Carbon (dmmfb) .....%	87.43	87.02	86.83	87.78
Proximate Analysis (db)				
Ash .....%	7.27	8.22	5.32	5.45
Volatile Matter .....%	36.03	34.59	35.81	35.43
Fixed Carbon .....%	56.70	57.19	58.87	
Gross Calorific Value (db)				
Btu per pound	14332	14333	14783	14668
Ultimate Analysis (db)				
Carbon .....%	80.31	78.85	81.54	81.40
Hydrogen .....%	5.24	5.16	5.32	5.34
Sulphur .....%	1.41	3.43	2.37	2.71
Nitrogen .....%	1.54	1.51	1.63	1.54
Ash .....%	7.27	8.22	5.32	5.45
Oxygen (by difference) .....%	4.23	2.83	3.82	3.56
Ash Analysis (db)				
SiO_2 .....%	32.04	32.23	24.14	31.63
Al_2O_3 .....%	20.95	18.29	17.49	21.21

Table 4 - Cape Breton Development Corporation - #12 Colliery Cont'd

Ash Analysis (db) Cont'd				
Fe_2O_3 .....%	37.67	45.45	49.74	41.35
TiO_2 .....%	0.62	0.40	0.35	0.52
P_2O_5 .....%	0.50	0.19	0.26	0.22
CaO .....%	2.94	1.02	2.11	1.19
MgO .....%	1.55	0.73	0.85	0.78
SO_3 .....%	2.18	0.91	1.46	0.80
Na_2O .....%	0.69	0.63	0.58	0.78
K_2O .....%	1.49	1.32	1.03	1.55
Forms of Sulphur				
Sulphate .....%				
Pyritic .....%				
Organic (by difference) .....%				
Total .....%				
Free Swelling Index	7½	6½	6¾	7½

Figure 1

Relationship Between Total Iron in the Coal

and the Iron Associated with Pyrite

Compared to Pyritic Sulphur

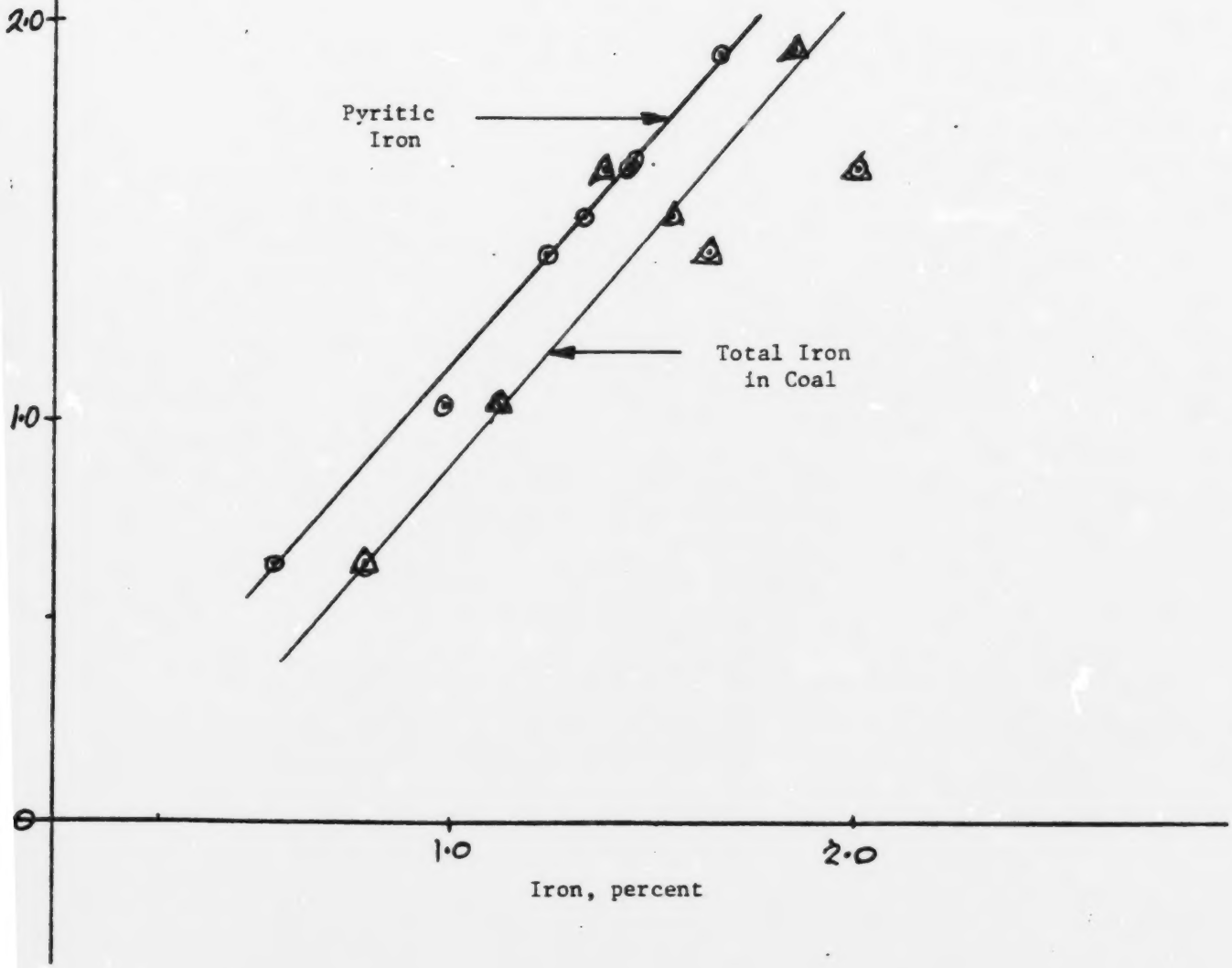

Figure 2 Washability Distribution Curves for Lingan Mine Coal

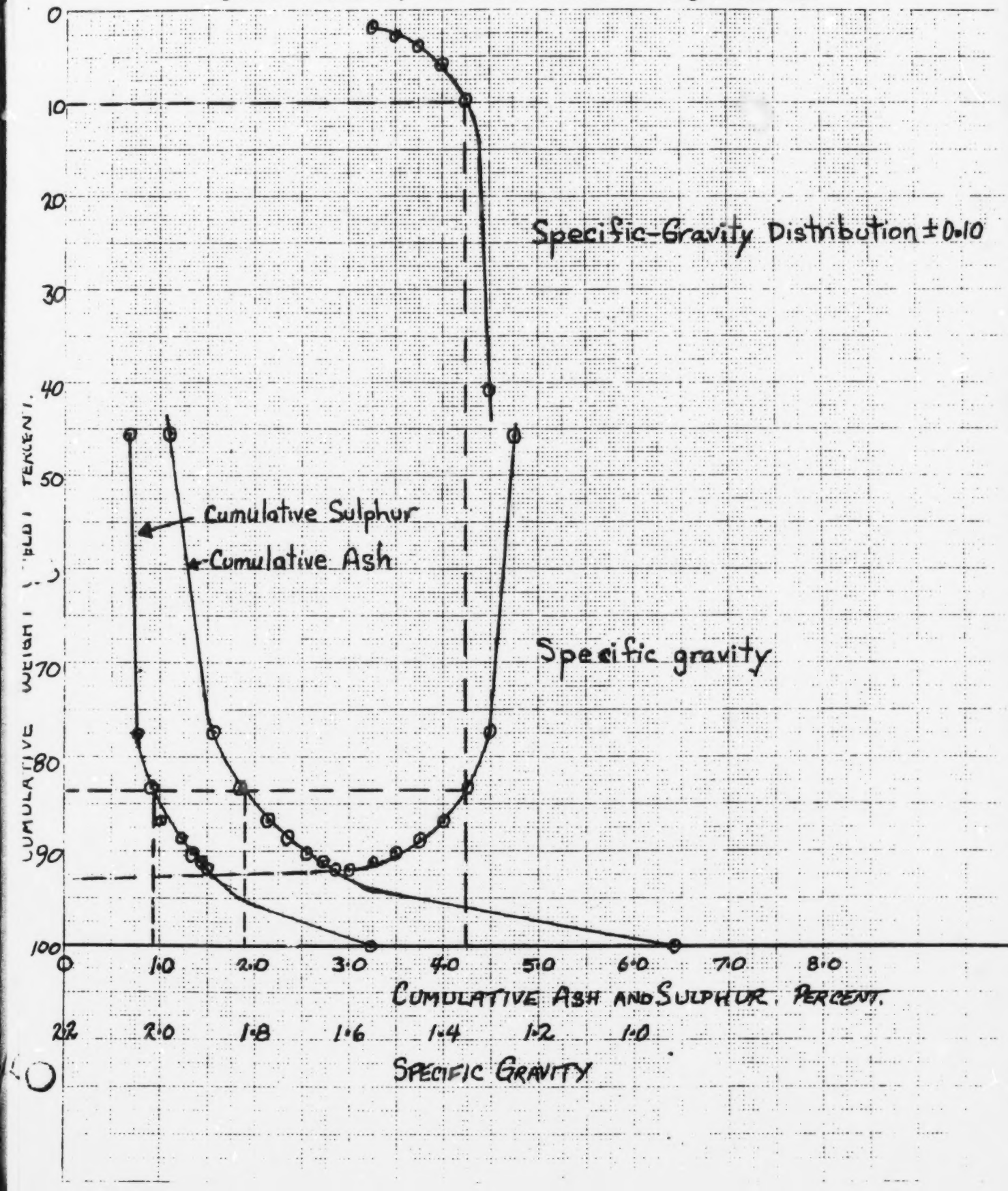

Table 5

Sample No.	Pyritic Sulphur	Fe in FeS_2 x0.871	Fe_2O_3 %	Fe in Fe_2O_3 x0.699	Ash %	Total Fe in coal	Diff. = Fe associated with other MM
2360-71	1.42	1.24	60.45	42.25	3.89	1.64	0.40
2654-71	1.51	1.32	35.27	24.65	6.29	1.55	0.23
2505-71	1.92	1.67	59.60	41.66	4.43	1.85	0.18
2504-71	1.64	1.43	36.34	25.40	5.40	1.37	-0.06
2917-71	0.64	0.56	27.52	19.24	4.04	0.78	0.22
2780-71	1.63	1.42	59.79	41.79	4.81	2.01	0.59
2995-71	1.14	0.99	45.20	31.59	3.54	1.12	0.13

Comments

Based on this data, one can evaluate the performance of the Centrix when analysing coal for total Fe and relating this to an estimate of pyrite present. In most cases, assuming 100% efficiency of the Centrix, a conversion factor could be applied to obtain the Fe associated with pyrite. Another conversion factor, or a combination of the two, could be applied to obtain the total pyrite present.

(2) Based on a 60% reduction in pyritic sulphur by accepted mechanical means, what is the average total sulphur value of the cleaned product?

Table 6

Sample No.	Ash %	Total Sulphur %	Pyritic Sulphur %	60% Removal of Pyritics	Total Sulphur after Reduction
2360-71	3.89	2.14	1.42	0.85	1.29
2354-71	6.29	1.92	1.51	0.91 .	1.01
2505-71	4.43	2.52	1.92	1.15	1.37

Table 6 Cont'd

Sample No.	Ash %	Total Sulphur %	Pyritic Sulphur %	60% Removal of Pyritics	Total Sulphur after Reduction
2504-71	5.40	2.78	1.64	0.98	1.80
2917-71	4.04	1.23	0.64	0.38	0.85
2780-71	4.81	2.93	1.63	0.98	1.95
2995-71	3.54	1.56	1.14	0.68	0.88
AVERAGE	4.63	2.15	1.41	0.85	1.30

Comments

Based on 60% removal of pyritic sulphur the arithmetic average sulphur of the cleaned Lingan Mine coal will be 1.30%.

Table 7

Sulphur Forms of Lingan Float and Sink Samples (FRC)

Sample No.	Specific Gravity	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Total S
3209-72	Float 1.25	0.00	0.13	0.52	0.65
3210	" 1.30	0.02	0.35	0.52	0.89
3211	" 1.35	0.04	2.11	0.79	2.94
3212	" 1.40	0.06	3.61	1.09	4.76
3213	" 1.45	0.11	5.23	1.42	6.76
3214	" 1.50	0.15	6.12	1.81	8.08
3215	" 1.55	0.15	6.48	2.45	9.08
3216	" 1.60	0.18	6.42	1.90	8.50
3217	Sink 1.60	0.38	21.93	0.46	22.67

Table 8

Washability Distribution Data (JGJ)

Sample No.	Specific Gravity	Yield %	Ash db, %	Sulphur db, %	Cumulative, %		
					Recovery, %	Ash, %	Sulphur, %
3209-72	1.25	45.6	1.09	0.67	45.6	1.09	0.67
3210	1.30	31.7	2.27	0.92	77.3	1.57	0.77
3211	1.35	5.9	5.55	3.01	83.2	1.85	0.93
3212	1.40	3.5	8.44	4.87	86.7	2.13	1.09
3213	1.45	1.9	12.40	6.90	88.6	2.35	1.21
3214	1.50	1.6	14.84	8.24	90.2	2.55	1.34
3215	1.55	1.0	16.60	9.24	91.2	2.72	1.43
3216	+1.60	0.7	18.92	8.64	91.9	2.85	1.48
3217	-1.60	8.1	47.06	22.95	100.0	6.43	3.22

Comments

1) Based on the ±0.1 S.G. distribution curve:

The point where 10% of the raw coal feed lies between ±0.10 S.G. indicates the lowest S.G. at which it is practical to operate a cleaning plant.

In this case, the S.G. is 1.35 and the theoretical recovery from the Specific Gravity Curve is 83.6 percent at an ash level of 1.9 percent and sulphur content of 0.95 percent.

2) Since the basic washery problem with this Cape Breton coal is not the reduction in ash but rather the lowering of the sulphur content, the coal should be washed at as low a density as possible. When washing at a high S.G. such as 1.60, much of the pyrite will remain locked in the intermediate-density fractions. However, it is generally accepted that recovery efficiency decreases with decrease in density of separation.

3) In order to free as high a percentage of pyrite from the coal, the ROM coal should be crushed as fine as possible. However, by standard wet washing methods it is very difficult to separate pyrite from coal in the fine size fractions.

Nevertheless, some success has been reported (Miller, F.G., Society of Mining Engineers, March, 1964) with a two stage flotation process with proper depressants. Hydrocyclones, because they separate primarily by specific gravity, are an effective means of removing pyritic sulphur. However, because they tend to throw extreme fines of all gravities to their clean coal product, they are best used in combination with froth flotation if high yields are to be obtained.

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